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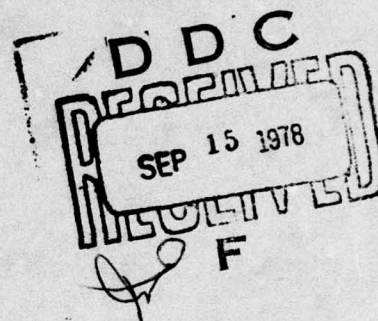
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LEVEL II

Design Factors in the Tuned Synthetic Aperture Radar

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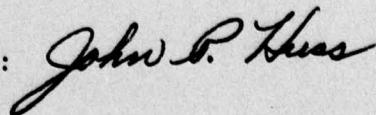
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The frequency filters are implemented by applying the discrete Fourier transform to the returning radar pulses. Proper selection of the particular outputs at which a target appears at a given time is the function of a computer program, for which the theoretical foundations and program logic are developed in the report. The program can be used to determine the specific factors to be programmed for processing return data and for designing the actual processor. The results show typical memory and time requirements for laboratory test-bed and operational processors.

Finally, a technique for reducing total memory required by reducing stored input data is described and developed. Tradeoffs between time and memory are discussed, and optimal operating point calculations are developed.

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Design Factors in the Tuned Synthetic Aperture Radar

1. INTRODUCTION

Since the late 1930s, one of the most impressive areas of technological development has been that of radar. However, in spite of our present expertise, the operational capability to detect and track slowly moving targets accurately, on or near the ground, from a swiftly moving airborne platform does not exist. The Tuned Synthetic Aperture Radar (TUSAR) technique aims at achieving that capability. The development of TUSAR would have its application in long-range battlefield surveillance. If mounted in a C-130, for instance, such a radar could inform a ground commander of the entire situation of moving men, armaments, and supplies, and never get closer than 40 miles from the action.

The mathematical and theoretical foundations for the Tuned Synthetic Aperture Radar have been laid.¹ One realization of the Tuned Synthetic Aperture Radar processing is evaluated in this paper.* The evaluation requires a computer program of sizeable magnitude. The program can be broken down readily into several sub-programs. The sub-program described herein determines the

(Received for publication 24 August 1977)

1. Schindler, J.K. and Goggins, W.B. An Airborne Radar Technique for Moving Target Detection, Location and Tracking, AFCRL-TR-73-0719.

* This work was conducted while one of the authors (RAL) was participating in a cooperative research program from the US Air Force Academy.

number of radar outputs, particular outputs, and number of data sets required for processing. The development of this sub-program came about in three stages, the first of which was determining the exact function to be performed and the use to which the results will be applied. The second stage involved developing program logic, and the third stage involved using actual data in the program to determine trends which might be useful in later design stages.

2. PROGRAM

The digital AMTI processing employed by the TUSAR technique is to be evaluated with a truck-borne test-bed radar operating at X band. The inphase and quadrature components of the received signal are digitized and processed in a signal processing oriented MAP300* mini-computer for doppler frequency selection. The signal is passed through a Fast Fourier Transform (FFT) of as yet undetermined size, and successive, contiguous doppler frequency outputs are linearly and coherently combined and detected to yield target detection data. Specifically, as the radar test vehicle moves, the complex amplitude of the received signal from each transmitted pulse is observed. When the returns from N pulses are received, they are batch processed by an FFT, yielding N doppler frequencies at the output. This process is repeated over M successive but not necessarily contiguous time periods of N pulses, allowing one to track the target by following its linear doppler frequency modulation over the $N \times M$ pulse period of time.

In general, the processor has $N \times M$ doppler frequency data points available. If only slowly moving targets are considered, a small portion of these $N \times M$ data points are needed. For instance, selecting the initial doppler frequency of the target in the range $-.1\omega_{cm}$ to $+.1\omega_{cm}$ (ω_{cm} = maximum doppler radian frequency of the ground clutter) and a maximum frequency change of $.2\omega_{cm}$ over the total radar integration time means that moving targets must appear in a doppler frequency band of width $.4\omega_{cm}$. The Nyquist sampling theorem requires a pulse repetition frequency of at least twice the highest frequency. That means the available FFT outputs cover a bandwidth of $2\omega_{cm}$ or more. Needing only $.4\omega_{cm}$ bandwidth to observe slowly moving targets allows us to ignore at least 80% of the possible FFT outputs. The resulting simplification in the processing, through pruning of the FFT algorithm, will be utilized here.

*The MAP300 is a high-speed digital signal processor manufactured by CSPI, Burlington, MA.

3. THE LINEAR DOPPLER FREQUENCY APPROXIMATION

The tuned Synthetic Aperture Radar technique is based on the idea that within a limited segment of the along track path of the radar, the doppler frequency shift of both constant velocity moving targets and stationary clutter is linear (Figure 1).

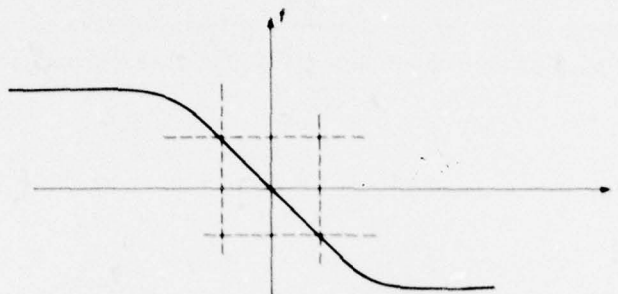


Figure 1. A Typical Doppler History, Showing Region of Linearity

This approximation improves as the doppler frequency bandwidth of the moving target and the limited segment of along track path decreases. The linear frequency approximation simplifies the process of detecting a moving target to postulating the slope and initial frequency of the target and then incrementing and coherently combining the doppler frequency output of the successive N point FFTs to coherently track the doppler frequency of the target. This is the basic process assumed in the development of a program which, given the frequency of entry and rate of frequency decreases of the moving target, provides a sequence of FFT outputs that coherently tracks the moving target over the integration time of the radar.

4. NEGATIVE FREQUENCIES

As indicated in Figure 1, the instantaneous doppler frequency of a moving target decreases with time. Targets will then exhibit negative frequencies. The program under development must allow for this problem in a system where nominally only positive frequencies occur at the FFT outputs. The sampling theorem is once again the key. Figure 2 shows the sample return frequency spectrum with its recurring patterns at harmonics of the radar pulse repetition

frequency, ω_{prf} . Negative frequencies are shifted to the next harmonic (see Figure 3), and read as positive frequencies just below ω_{prf} . As the target's doppler frequency decreases, it moves from right to left in the shaded area commencing at A. When the target reaches zero doppler frequency it jumps to ω_{prf} , then continues to shift from right to left as though passing through negative frequencies. The output of each N point FFT is N different frequencies ranging from zero to ω_{prf} . Numbering each of these with an integer value from 1 to N provides a convenient way of referencing the particular outputs to be used, as well as telling us how many of the outputs are needed for slow-moving target detection.

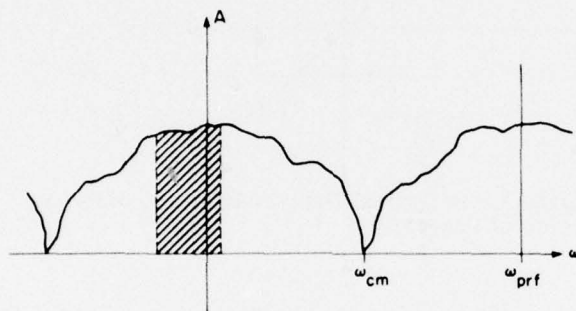


Figure 2. Received Signal Spectrum With Range of Target Frequencies

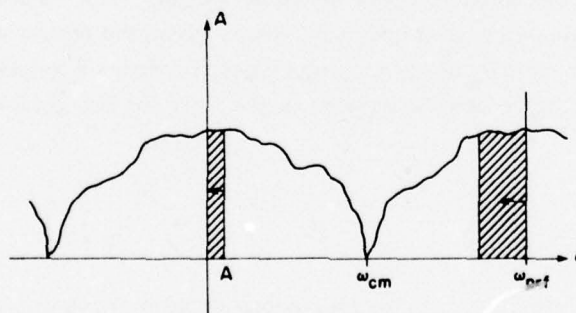


Figure 3. Received Signal Spectrum With Shifted Range of Target Frequencies

Assuming that the moving targets occupy 40% of the maximum clutter frequency, ω_{cm} , and that clutter is barely unambiguous, ($\omega_{prf} = 2\omega_{cm}$), then the number of FFT outputs required are

$$\frac{.4\omega_{cm}}{2\omega_{prf}} N = \frac{.4f_r V_r}{cPRF} N = .2N.$$

Here f_r is the radar carrier frequency, V_r is platform velocity, PRF is pulse repetition frequency, and c is speed of light.

5. FREQUENCY INTERVALS

The frequency and time scales of the observations are conveniently divided into blocks of N/PRF time units, and PRF/N frequency units. These units are derived from the fact that each FFT requires N pulses, and each interpulse time is $1/PRF$. Hence, there are N/PRF time units per block. Since the frequencies at the outputs range from 0 to ω_{prf} , and there are N of these outputs, there must be PRF/N radians per second per block. Figure 4 depicts these "blocks" graphically. They are intervals of interest with integer assignments and constant width or height.

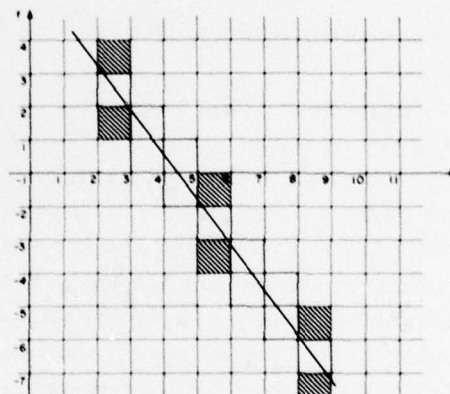


Figure 4. Division of Time and Frequency Intervals With Postulated Target Type Superimposed

These blocks, or "bins," represent the possible time-frequency combinations that a target can attain. In Figure 4, a line has been drawn to represent a postulated moving target. Each box through which this line passes indicates an FFT output at a certain time where the target signal will appear. Notice, however,

that there are bins which are barely touched by the target and which should perhaps be ignored since the contribution to improving the target signal to clutter of these bins is minimal. This condition, indicated by shaded boxes, means that one should selectively omit certain bins from the output processing. This process may be accomplished by a percentage lop-off procedure, which observes the fraction of time a target spends passing through a bin and ignores those bins that contribute little.

6. LIMITS ON THE TRACE

The basic problem at hand is to filter clutter and improve the target signal-to-clutter ratio. A decision must be made at this point. Should the search for a postulated target pass through a fixed number of frequency bins, allowing the number of time intervals to change, or would the SCR be greater by tracking each target type for a given number of time periods, allowing the number of frequency bins occupied by a target to vary? Although no quantitative analysis was performed, intuition coupled with qualitative arguments suggested using a fixed number of frequency bins for each target, regardless of the time frame needed. Thus, the algorithm was designed to select a start frequency and terminate track after a frequency change of $0.2\pi_{cm}$ was achieved.

7. PURPOSE OF THE PROGRAM

The purpose of this program is twofold. The first is the most obvious; it shows the exact succession of FFT outputs needed for target detection, how many are required for each time period, and how much memory is required. The other purpose is more subtle. The FFT output in each time-frequency bin is to be weighted and coherently added to others to form a single detection statistic. The relative weighting factor can be found by applying signal-to-clutter maximization techniques described by Goggins and Schindler.^{1,2} The matrices involved in determining the maximum signal-to-clutter weighting factors are dependent upon the sequence of FFT outputs which are assumed to be combined. The program described here was designed to evaluate the successive FFT outputs required for processing. Future work will address the design of the relative weights required for coherent processing of these FFT outputs.

2. Goggins, W.B. and Schindler, J.K. Processing for Maximum Signal-to-Clutter AMTI Radars, AFCRL-TR-74-0577.

How are specific target parameters chosen for design purposes? Obviously, there is an infinitely large set of unique velocities and ranges to be considered. Initially, this set of target parameters must be constrained to lie within certain bounds determined by the maximum ground speed of the target and its maximum and minimum range. Then, a finite, discrete set of target speed and direction pairs, as well as a set of target ranges, must be selected to serve as design parameters. Targets whose parameters fall in the gaps between the selected design parameters must be detected by virtue of the finite resolution of the processing. With the speed available in modern digital processing equipments, it appears quite possible to think of processing 200-300 general-target types in the time required to gather 512 pulses of raw data at UHF radar frequencies.

8. PROGRAM LOGIC

Having provided the basis for the program's development, it is time to discuss the logic involved. The program, written in Fortran (extended) for the CDC6600, consists of five basic stages. The first stage is a simple interactive scheme for inputting data through a remote terminal and spotchecking input data. This stage includes program lines 100 through 330 (a listing of the computer program is given in Appendix 1.) In the next stage (lines 380 to 590), the radar and target parameters discussed by Schindler and Goggins¹ are evaluated.

Lines 590 through 1280 contain the main iteration loop. After calculating the doppler frequencies where the target enters and leaves a specific time interval, the first step is to determine whether the target contributes significantly to the output power from an FFT filter during that interval. The procedure is to compare the portion of the frequency axis intercepted by the target with the total length of the frequency interval, that is, the bandwidth of the FFT filter. If a specified percentage (LOP) is not met or exceeded, that frequency-time interval is eliminated. Figure 5 illustrates this process at entering and exiting sides for slopes for less than -1. This case applies when the target doppler bandwidth during the time observation interval N/PRF exceeds the FFT filter cycle bandwidth, PRF/N . When the slope is greater than -1 (Figure 6) the time excursion of a target is compared to the whole time interval, N/PRF , to determine acceptable targets. In each figure, line segment 1 as a percentage of line segment 2 is compared to the parameter LOP to determine acceptable targets.

Having decided what bins to ignore, the program goes on to store acceptable bin numbers for later output. There are three possible cases here. Either the time interval contains all positive frequencies, some positive and some negative frequencies or all negative frequencies. After recording all the bin numbers for

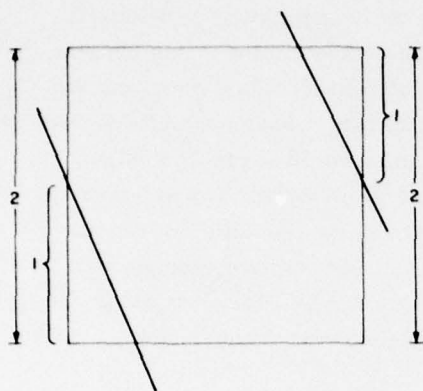


Figure 5. LOP Rate; Slope < -1

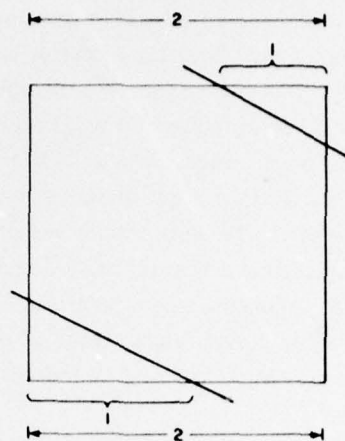


Figure 6. LOP Rate; $-1 < \text{Slope} < 0$

the interval in one of the three categories, the program steps to the next time interval and repeats. Lines after 1290 then output the computed information in three forms: input parameters, specific outputs numbered sequentially and within each FFT, and number of outputs, chops, and time intervals involved.

9. INDICATIVE TRENDS

Once completely debugged, the program was ready for use in theoretical case studies. One of the first studies performed was to change the FFT size and LOP rate, holding all radar and target parameters constant, and observe the number of FFT outputs required. The results of this study are plotted on two graphs, Figures 7 and 8. Figure 7 shows a linear decrease in the number of FFT outputs required as a function of the LOP rate. This fact indicates that we can freely change the LOP rate to achieve the desired number of outputs. Figure 8 points out two interesting facts. First, as a function of FFT size and hence FFT bandwidth, there is a point where the number of bins accepted is at a minimum. The minimum occurs when the average frequency change during an FFT observation time, N/PRF equals the FFT bandwidth PRF/N . The curve is parabolic when the abscissa is defined in \log_2 units. The second interesting fact is that, at the minimum, the number accepted is a sensitive function of the LOP rate. This is manifested in the spread between the curves at the minima, as compared to elsewhere on the curve.

Another interesting effect was noticed. As the FFT size increases, the number of time periods required decreases. The overall effect is to produce a

Figure 7. Outputs Required vs. LOP Rate; Each Line an FFT Size

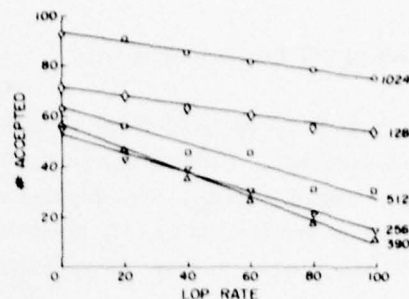
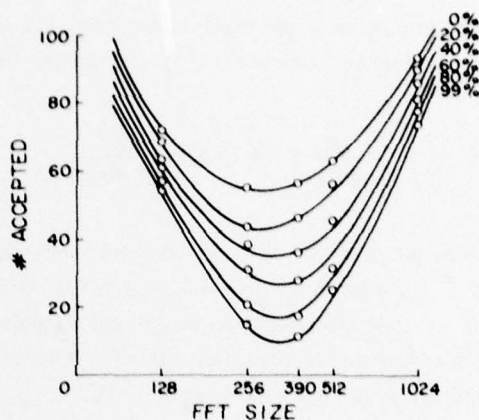


Figure 8. Outputs Required vs. FFT Size; Each Line a Different LOP Rate



reasonably constant total number of outputs to be stored for processing. Should a designer, for reasons of resolution or computation speed, want to change the FFT size, he can be assured such a change will not drastically affect the memory allocations.

On the other hand, additional studies indicated that there can be as much as a 70% change in the memory requirements when target and platform velocities are adjusted. This means that the ranges of all parameters will necessarily have to be decided upon just before the memory structure is designed.

Also of interest was the fact that, in the 0% LOP case, changing the FFT size produces "glitches" in the parabolic curves of Figure 8—areas of spikes where the number of outputs accepted suddenly increases. This is due to the digitization process which tries to fit the straight-line doppler history into a series of intervals. These spikes, however, tend to be smoothed at higher LOP rates.

10. SLOPE-FFT SIZE CALCULATIONS

As shown in Figure 8, there is an FFT size where the fewest number of outputs are accepted. This occurs when the average slope of the target doppler history is negative unity. The doppler rate or slope is proportional to the change in target doppler frequency, Δf , observed in a time period compared to the size of the FFT frequency interval, $F1$. That is, the slope, m , is given by

$$m = \Delta f / F1.$$

Now Δf can be expressed as the target doppler rate times length of time considered. The frequency interval, $F1$, is merely PRF/N . Thus

$$m = \frac{\dot{\omega}}{2\pi} \frac{N}{\text{PRF}} / \text{PRF}/N = \frac{\dot{\omega} N^2}{2\pi (\text{PRF})^2}.$$

A reasonable set of target doppler rate parameters lies between $1.21\dot{\omega}_{\text{cm}}$ and $.81\dot{\omega}_{\text{cm}}$, where $\dot{\omega}_{\text{cm}}$ is the maximum doppler rate of stationary clutter elements. This range corresponds to ground targets traveling at a speed which is, at most, 10% of the radar platform speed. It is thus reasonable to use $\dot{\omega}_{\text{cm}}$ for the target doppler rate in the above formula form, since $\dot{\omega}_{\text{cm}}$ is at the approximate mean of the target doppler rates.

From (1)

$$\dot{\omega}_{\text{cm}} = - \frac{4\pi f_r V_r^2}{R_t C}$$

where R_t = range to the target.

Then

$$m = - \frac{4\pi f_r V_r^2 N^2}{R_t C} 2\pi (\text{PRF})^2$$

$$= - \frac{2f_r V_r^2 N^2}{R_t C (\text{PRF})^2}.$$

To find the relative minimum in the curve of accepted outputs versus FFT size (Figure 8), allow $m = -1$ and solve for N :

$$N = \sqrt{\frac{R_t C}{2f_r}} \left(\frac{\text{PRF}}{V_r} \right).$$

The value of N specified here gives the optimal match of FFT bandwidth of ground clutter doppler excursion during the N/PRF integration time. Individualities in the moving targets doppler properties may change slightly where this minimum occurs.

11. PROCESSOR REQUIREMENTS

Numerous calculations and estimates were made to insure that the entire processor function could be performed within the time and memory limits of the truckborne CSP-30/MAP300 processor, and would later be practical in an aircraft. To start with, the processing time requirements in the truckborne case were examined. There are basically four functions for the central processor to perform: multiplication, addition, memory retrieval and counter update. The maximum time allowable for any processing of a given data set is going to be the time it takes to collect N data points. After calculating the computational times, a good estimate would be to double that time to allow for program execution. The chart given in Figure 9 shows these times. The times are based upon the truck case requiring summation of 50 complex numbers, each multiplied by its own weighting factors. It is assumed that the radar PRF is 1831 Hz, and 512 point FFTs are required in a test for 200 possible target doppler/doppler rate combinations. The reader should note that these are not intended as exact numbers, but rather are approximations to prove that processing time will not be a limiting factor. The FFT process will be run simultaneously on a different part of the processor, requiring only 4.5 ms for a 1024 complex point FFT, and will be idle 98.4% of the time. Overall, the speed with which the computations take place allows a vast number of target possibilities to be examined without stressing the real-time processing capabilities of the CSP-30.

The other major constraint on computational abilities is the size of the memory. The CSP-30 has an existing 32K word memory available, each word having 16 bits. Figure 10 shows a breakdown of the various memory requirements. These numbers assume the truckborne case of 40 time periods, 200 tasks, 50 summations per target, and only 1 memory access value needed for each data point. They also assume a rectangular matrix structure for memory, for which

FUNCTION	CSP 30 UNIT TIME	TOTAL TIME
200 MULTIPLIES	1100 nsec	220 μ sec
100 ADDS	400 nsec	40 μ sec
100 MEMORY RETRIEVALS	300 nsec	30 μ sec
50 COUNTER UPDATES	200 nsec	10 μ sec
		300 μ sec
200 REPETITIONS	300 μ sec	60 msec
PROGRAM EXECUTION		60 msec
	TOTAL	120 msec
DATA COLLECTION TIME (512 pt FFT)		280 msec

Figure 9. Computation Times

DATA POINTS:

40 TIME PERIODS
103 POINTS SAVED EACH FFT
x 2 WORDS PER COMPLEX WORD
8240 TOTAL WORDS

MEMORY REFERENCE SEQUENCES

50 POINTS/SUMMATION
x 200 SUMMATIONS
10,000 TOTAL WORDS

Figure 10. Memory Requirements

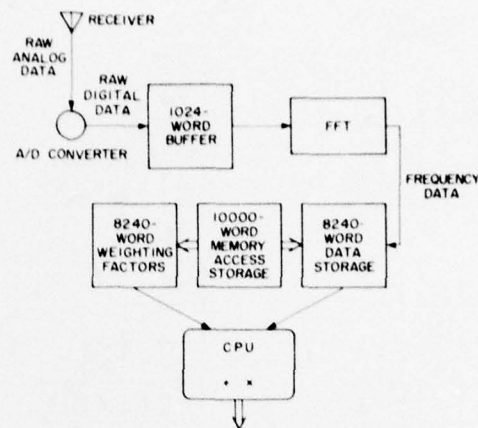
	WORDS
DATA POINTS	8240
WEIGHTING FACTORS	8240
REFERENCE SEQUENCES	10000
RAW DATA FOR FFT	1024
TOTAL	27504 WORDS
MEMORY REMAINING FOR PROGRAM EXECUTION	5264 WORDS

an alternative will be discussed later. Once again, the estimates provided in this figure are not exact. Rather, they are estimates which show that memory limitations appear to be more severe than processing time limitations in implementing this form of TUSAR processing. Stress should then be placed on programs which economize memory should actual requirements dictate.

Figure 11 takes a look at a block diagram representation of memory allocations.

It is important to remember that evaluated processing time and storage requirements apply to 200 moving target doppler/doppler-rate combinations in a single range "bin." At a distance of 400 m, we will be confined to observing objects within an 18 M range resolution cell. For other range resolution cells, one must add another dimension to the time and memory requirement calculations

Figure 11. Data Flow and Memory Requirements



or reduce some of the 200 dopplers/doppler-rate combinations/ in favor of additional range coverage. For the truck case, it will generally be necessary to consider only one range interval at a time.

12. SHORTER MEMORY

One unique method for cutting down on memory requirements is to use a triangular rather than rectangular array of data storage. Once the size of the FFT has been established, there are a fixed number of frequency bins and time periods to be considered. In the previous memory calculations, a rectangular array of fixed size was used to compute the memory size, and was valued at 80×103 words. This rectangular array of data assumes a need to keep every output from all integration time intervals for all calculations, which is not necessarily the case. Because of the linear decrease in target doppler frequency with time, the later in time an FFT output is required for a particular coherent summation, the less likely will be the requirement for a high-frequency output. It becomes clear that reduced memory results from saving only those low-frequency FFT outputs likely to be used. If, after FFT processing, new FFT output data is stored onto the high-frequency data points of previous FFTs, a triangular matrix results that requires 25% to 50% less memory. The reduced memory formation requires additional memory and time for keeping track of all the data locations presently in the memory structure.

A highly simplified version of the triangular storage format is displayed in Figure 12. Within each triangular memory array, a column represents a specific FFT frequency output. Numbers represent the time sequence during which the

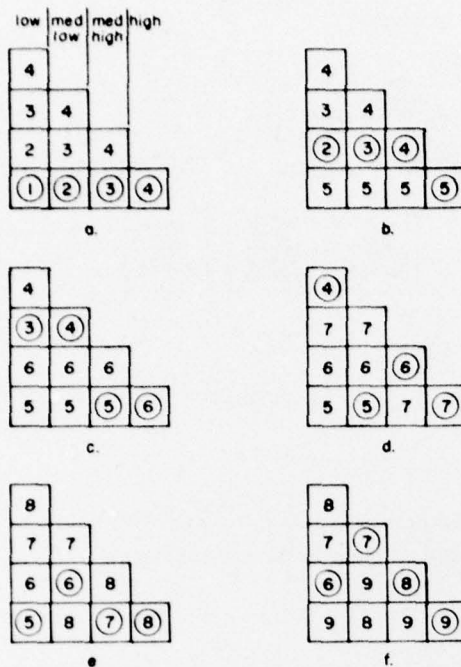


Figure 12. Triangular Data Structure (Simplified). Circled numbers represent outputs summed that time period, columns are frequencies, numbers are FFT number (highest most recent).

FFT outputs are generated and stored. Circled numbers represent data which is combined to produce the detection statistic and hence memory locations available for new data. In progressing from (a) to (f) in Figure 12, it is clear how new FFT data replaces data which has just been used. Only the low-frequency outputs, which will be used as the FFT grows old and the time axis shifts, are saved the whole time. The higher the frequency, the sooner it is used and discarded. Of course, this procedure will work best if the FFT size is predetermined, allowing the programmer to be sure that certain outputs can, indeed, be overwritten.

In greater detail, here is how the data structure of Figure 12 works. The data from FFT is initially set along diagonals, and counters for each frequency column are set to the base of the triangle. Each time period, circled data points are used. These memory locations become available to store the next FFT outputs.

Note in Figure 12 that the column counters only need to count up to the top of each column, reset, and begin counting up again. Thus, one needs only as many counters as one has frequencies.

The properties of the triangular memory structure as assumed target parameters change are of interest. The closer the target slope m is to -1 , the more triangular is the structure. As the slope shallows, the data structure appears more like a cornered rectangle (Figure 13). This is due to the fact that at shallow

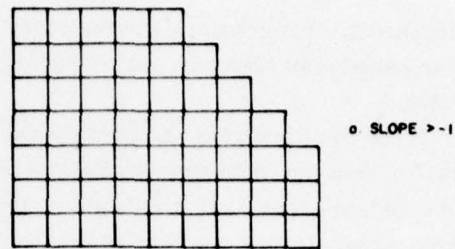
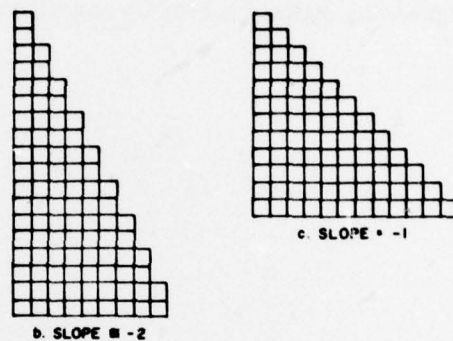


Figure 13. Data Structures for Different Slopes



slopes, a given frequency will be used a few times, rather than once. At steeper slopes, several frequencies may be thrown away at once, so an even smaller triangle is required in terms of relative dimensions, but the number of data points included increases, so that a tradeoff does, indeed, occur.

13. CONCLUSION

It is clear that the design of an efficient TUSAR processor is not a simple task. Care must be taken to trade off integration time, memory and computation load in selecting the appropriate FFT size. Interface between the radar video data and processor, and between the summation output and display, must be considered. One must also consider the magnitude of the problem: a postulated target can have any velocity vector magnitude and direction, and the radar platform can look at any of a number of ranges for a variety of platform velocities, yielding a four-dimensional array of reference data.

Despite the obvious complexities, the project is by no means hopeless. Time and memory restrictions do not severely limit laboratory project scope or

capabilities. Programming parameters are not highly sensitive to target and radar parameter changes, particularly if a triangular memory allocation system is used.

In the final analysis, an operational model will be an order of magnitude more complex than the laboratory model of the radar. As few pilots are willing to fly at a constant speed over a straight course for any length of time in a combat environment, larger memory is required along with the use of plug-in PROM cards to accommodate different aircraft speeds. The use of the TUSAR technique on board a C-130 or similar aircraft is realistic, and apparently lies within our progressing digital processing capabilities.

Appendix A

Listing and Sample Outputs

This Appendix contains a listing, and sample outputs for the computer program described in Section 8.

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```

PROGRAM WIRESET (INPUT,OUTPUT,TAPE6)                                000100
INTEGER WIRESET(200)                                                000110
DIMENSION WIRESET(200)                                              000120
REAL P1,ANS,WO,WDOCH,WDOCT,WCM,RTA,RTH,VTA,VTM,LOP,VR,FR,DELM,    000130
TINC,INTER,NUM,IL,L,M,PRF                                          000140
INTEGER NUM,YNUM                                                    000150
REWIND 6                                                            000160
PRINT 80                                                            000170
80  FORMAT ('* TYPE IN TARGET RANGE (METERS), AZIMUTH (DEGREES), AND VE 000180
10  LOCITY (METERS/SEC, DEGREES),')                                000190
READ *,RTH,RTA,VTM,VTA                                             000200
PRINT 81                                                            000210
81  FORMAT ('* TYPE IN PLATFORM VELOCITY (METERS/SEC), PRF (HZ), * 000220
10  CARRIER FREQ. (MCZ), LOP OFF RATE (1), AND FFT SIZE.,')    000230
READ *,VR,OPF,FO,LOP,NUM                                           000240
PRINT 82                                                            000250
82  FORMAT ('* THESE ARE THE NUMBERS YOU GAVE ME: CHECK THEM.*') 000260
READ *,RTH,RTA,VTM,VTA,VR,OPF,FO,LOP,NUM                         000270
PRINT 83                                                            000280
83  FORMAT ('* ARE THEY CORRECT? (0 MEANS NO, 1 MEANS YES)')      000290
READ *,ANS                                                         000300
IF (ANS.EQ.0) GO TO A4                                             000310
PT=3.14159265358979324                                            000320
LOP=LOP/100 $ FR=FR*10**6                                         000330
C  FIND CLUTTER AND RADAR PARAMETERS                                000340
C  IR=0 $ IO=0                                                      000350
C  WCM=4*PI*FR*VR/(3*10**8)                                         000360
C  WDOCH=4*PI*FR*VR**2/(RTH*3*10**8)                               000370
C  DELM=2*PI*PRF/NUM                                                 000380
C  TINC=2*PI*1/DELM                                                  000390
C  RESOLVE THE ANGLES TO RADIANS                                    000400
C  RTA=PI*RTA/180                                                    000410
C  VTA=PI*VTA/180                                                    000420
C  FIND THE RECTANGULAR COORDINATES OF DELTA V BAR AND            000430
C  THETA SUB 0 DEL V.                                              000440
C  ADELV=VR*VTM*COS(VTA)                                            000450
C  BDELV=-VTM*SIN(VTA)                                              000460
C  ANGOV=RTA-ATAN2(BDELV,ADELV)                                     000470
C  FIND THE TARGET PARAMETERS                                       000480
C  WO=4*PI*FR*SQRT(ADELV**2+BDELV**2)*COS(ANGOV)/(3*10**8)        000490
C  WDOCT=-4*PI*FR*(ADELV**2+BDELV**2)*SIN(ANGOV)**2/(RTH*3*10**8) 000500
C  END OF PARAMETER FINDING. NOW BEGIN SEARCH ROUTINE.           000510
C  N=1 $ IZ=0                                                        000520
C  WF=WO-0.2*WCM $ LF=INT(WF/DELM)                                000530
C  IF (WF.LT.0) LF=LF-1                                             000540
C  CALCULATE ENTERING AND EXITING FREQUENCIES FOR GIVEN TIME INTERVAL 000550
C  L=INT(WO/DELM)+1                                                 000560
C  IF ((WF/DELM).LT.0) L=L-1                                         000570
C  WBEQ=WDOCT*TINC*(N-1)+WO                                         000580
C  WSTOP=WDOCT*TINC*N+WO                                            000590
C  FIND INTEGER VALUE OF EXIT FREQUENCY INTERVAL                  000600
C  M=L                                                                000610
M=L                                                                000770

```

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```

10 M=M-1
11 IF ((M*DELW).GT.WSTOP) 10,11
12 IF (M.LE.L) GO TO 12
13 IF ((-WDOIT*YINC.LT.DELW) 50,59
14 IF ((WREG-(L-1)*DELW).LT.(LOP*DELW)) 30,31
15 IL=L-1 & IR=IR+1 & GO TO 35
16 IL=L
17 IF (((M+1)*DELW-WSTOP).LT.(LOP*DELW)) 32,33
18 IM=M+2 & IR=IR+1 & GO TO 36
19 IM=M+1 & GO TO 36
20 IF ((WREG-(L-1)*DELW)/(-WDOIT)).LT.(LOP*YINC) 50,51
21 IL=L-1 & IR=IR+1 & GO TO 55
22 IL=L
23 IF (((M+1)*DELW-WSTOP)/(-WDOIT)).LT.(LOP*YINC) 52,53
24 IM=M+2 & IR=IR+1 & GO TO 36
25 IM=M+1 & GO TO 36
26 WE HAVE JUST ALLOWED FOR SWEEP WHICH DOES NOT CUT A LARGE
27 ENOUGH CORNER FROM A TIME-FREQUENCY INTERVAL (BOX).
28 IF (IM.GT.IL) GO TO 22
29 IF (IM.GT.0.AND.IL.GT.0) 13,14
30 DO 15 I=IM,IL
31 WIRES(IZ)=(N-1)*NUM+I
32 IZ=I+1
33 GO TO 22
34 IF (IL.GT.0.AND. IM.LE.0) 16,17
35 DO 18 I=1,IL
36 WIRES(IZ)=(N-1)*NUM+I
37 IZ=I+1
38 ZNUM=NUM+IM
39 DO 19 I=ZNUM,NUM
40 WIRES(IZ)=(N-1)*NUM+I
41 IZ=I+1
42 GO TO 22
43 IF (IL.LE.0.AND. IM.LE.0) 20,21
44 ZNUM=NUM+IM & YNUM=NUM+IL
45 DO 24 I=ZNUM,YNUM
46 WIRES(IZ)=(N-1)*NUM+I
47 IZ=I+1
48 GO TO 22
49 FORMAT (1H,3X,'ERROR--LOWER ROUND.N GREATER THAN UPPER BOUND L. ')
50 GO TO 22
51 L=M+1 & N=N+1 & WREG=WSTOP
52 GO TO 4
53 GO INTO OUTPUT MODE
54 CONTINUE
55 FORMAT (1H, TARGET IS AT RANGE *.F0.1,* METERS, BEARING *.F5.1,
56 1* DEGREES FROM FLIGHT PATH.*/,* TARGET VELOCITY IS *,
57 1*4.2,* METERS/SEC AT RELATIVE BEARING *.F5.1,
58 1* DEGREES
59 1* LOA DATE IS *.F0.1,* PERCENT.*/
60 1* RADAR IS SET UP AS FOLLOWS\*,/,5X,
61 1* VELOCITY\*,*.F6.2,* METERS/SEC.*/7,5X,
62 1* PROF *.I5,* HERTZ.*/5X,
63 1* CARDIEN\*,*.E4.3,* HERTZ.*/5X,
64 1* EACH FFT IS *.I4,* POINTS LONG.*/
65 RTA=RTA*180/PI & VTA=VTA*180/PI & LOP=LOP*100
66 PRINT (6,71) RTA,VTA,VTM,VTA
67 PRINT (6,72) LOP
68 PRINT (6,73) VR,PRF,FR,NUM
69 FORMAT (1H, W0= *.F5.2,* TIMES WCH.*/5,
70 1* WDOIT = *.F5.2,* TIMES WDOIT.*/
71 1* WE REQUIRE *.I3,* OUTPUTS AS FOLLOWS\*,/,
72 1* POSITION FFT OUTPUT # *)
73 FORMAT (1X,13,5X,16,9X,14)
74 PERDOT=WDOIT/WDOIT & PERB=W0/WCH
75 PRINT (6,74) PER0,PERDOT
76 PRINT (6,75) IZ
77 J=0 & IS=0
78 LZ=WIRES(IZ)-NUM*J
79 IF (L7.GT.NUM) 40,41
80 J=J+1
81 GO TO 42
82 PRINT (6,76) IS,WIRES(IZ),LZ
83 ID=ID+1
84 T=T+1

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```

IF(15.GT. (12 - 1)) 43, 42
43 PRINT (6,101) IR, IQ
PRINT 101,IR,IQ
N=4-1
PRINT 102,N
PRINT 101,102,N
101 FORMAT(20,13,* CHOPS MADE,*,/5X,13,* OUTPUTS LEFT,*)
102 FORMAT(5X,13,* TIME PERIODS ELAPSED,*)
PRINT 78
78 FORMAT(* DO YOU WANT TO TRY AGAIN? (0=NO, 1=YES)* )
READ *,ANS
IF(ANS.EQ.1) GO TO 84
STOP
END

```

001640
001650
001660
001670
001680
001690
001700
001710
001720
001730
001740
001750
001760
001770

TARGET IS AT RANGE 50000.0 METERS, BEARING 90.0 DEGREES FROM FLIGHT PATH.
TARGET VELOCITY IS 3.86 METERS/SEC AT RELATIVE BEARING 45.0 DEGREES (RIGHT WING POSITIVE).
LOP RATE IS 50.0 PERCENT.

RADAR IS SET UP AS FOLLOWS\

VELOCITY\	154.33 METERS/SEC.
PRF\	250 HERTZ.
CARRIER\	.100E+09 HERTZ.
EACH FFT IS	512 POINTS LONG.
WD=	~.02 TIMES WCM.
WDOTT =	.96 TIMES WDOTCM.

WE REQUIRE 39 OUTPUTS AS FOLLOWS\

	POSITION	FFT OUTPUT #
0	508	508
1	509	509
2	1019	507
3	1529	505
4	1530	506
5	2040	504
6	2551	503
7	3062	502
8	3572	500
9	3573	501
10	4083	499
11	4594	498
12	5104	496
13	5105	497
14	5615	495
15	6126	494
16	6637	493
17	7147	491
18	7148	492
19	7658	490
20	8169	489
21	8679	487
22	8680	488
23	9190	486
24	9701	485
25	10212	484
26	10722	482
27	10723	483
28	11233	481
29	11744	480
30	12254	478
31	12255	479
32	12765	477
33	13276	476
34	13787	475
35	14297	473
36	14298	474
37	14808	472
38	15319	471

31 CHOPS MADE.
39 OUTPUTS LEFT.
30 TIME PERIODS ELAPSED.

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TARGET IS AT RANGE 50000.0 METERS, BEARING 93.0 DEGREES FROM FLIGHT PATH.
TARGET VELOCITY IS 3.86 METERS/SEC AT RELATIVE BEARING 0.0 DEGREES (RIGHT WING POSITIVE).
LOP RATE IS 50.0 PERCENT.

RADAR IS SET UP AS FOLLOWS:
VELOCITY\ 154.33 METERS/SEC.
PRF\ 250 HERTZ.
CARRIER\ .100E+09 HERTZ.
EACH FFT IS 512 POINTS LONG.
WDW = -.00 TIMES WCM.
WDOT = .95 TIMES WDOTCH.

WE REQUIRE 39 OUTPUTS AS FOLLOWS:

	POSITION	FFT OUTPUT #
0	512	512
1	1022	510
2	1023	511
3	1533	509
4	2044	508
5	2555	507
6	3065	505
7	3066	506
8	3576	504
9	4087	503
10	4598	502
11	5108	500
12	5109	501
13	5619	499
14	6130	498
15	6641	497
16	7151	495
17	7152	496
18	7662	494
19	8173	493
20	8683	491
21	8684	492
22	9194	490
23	9704	489
24	10216	488
25	10726	486
26	10727	487
27	11237	485
28	11748	484
29	12259	483
30	12769	481
31	12770	482
32	13280	480
33	13791	479
34	14302	478
35	14812	476
36	14813	477
37	15323	475
38	15834	474

32 CHOPS MADE.
39 OUTPUTS LEFT.
31 TIME PERIODS ELAPSED.

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TARGET IS AT RANGE 50000.0 METERS, BEARING 90.0 DEGREES FROM FLIGHT PATH.
TARGET VELOCITY IS 3.86 METERS/SEC AT RELATIVE BEARING 135.0 DEGREES (RIGHT WING POSITIVE).
LOP RATE IS 50.0 PERCENT.

RADAR IS SET UP AS FOLLOWS\

VELOCITY\	154.33 METERS/SEC.
PRF\	250 HERTZ.
CARRIER\	.100E+09 HERTZ.
EACH FFT IS 512 POINTS LONG.---	
WD=	-.02 TIMES WCH.
WDOT =	1.04 TIMES WDOTCH.

WE REQUIRE 39 OUTPUTS AS FOLLOWS\

	POSITION	FFT OUTPUT #
0	508	508
1	509	509
2	1019	507
3	1529	505
4	1530	506
5	2040	504
6	2550	502
7	2551	503
8	3061	501
9	3572	500
10	4082	498
11	4083	499
12	4593	497
13	5103	495
14	5104	496
15	5614	494
16	6125	493
17	6635	491
18	6636	492
19	7146	490
20	7657	489
21	8167	487
22	8168	488
23	8678	486
24	9188	484
25	9189	485
26	9699	483
27	10210	482
28	10720	480
29	10721	481
30	11231	479
31	11742	478
32	12252	476
33	12253	477
34	12763	475
35	13273	473
36	13274	474
37	13784	472
38	14295	471

29 CHOPS MADE.
39 OUTPUTS LEFT.
28 TIME PERIODS ELAPSED.

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69 6146 124

TARGET IS AT RANGE 50000.0 METERS, BEARING 90.0 DEGREES FROM FLIGHT PATH.
TARGET VELOCITY IS 3.86 METERS/SEC AT RELATIVE BEARING 49.8 DEGREES (RIGHT WING POSITIVE).
LOP RATE IS 50.0 PERCENT.

RADAR IS SET UP AS FOLLOWS:
VELOCITY 154.33 METERS/SEC.
PRF 250 HERTZ.
CARRIER 1000.09 HERTZ.
EACH FFT IS 2048 POINTS LONG.
WOM = .82 TIMES WOM.
WOOT = .94 TIMES WOOTCM.

WE REQUIRE 165 OUTPUTS AS FOLLOWS:

	POSITION	FFT OUTPUT #
0	2014	2014
1	2015	2015
2	2016	2016
3	2017	2017
4	2018	2018
5	2019	2019
6	2020	2020
7	2021	2021
8	2022	2022
9	2023	2023
10	2024	2024
11	2025	2025
12	2026	2026
13	2027	2027
14	2028	2028
15	2029	2029
16	2030	2030
17	2031	2031
18	2032	2032
19	2033	2033
20	2034	2034
21	4041	1993
22	4042	1994
23	4043	1995
24	4044	1996
25	4045	1997
26	4046	1998
27	4047	1999
28	4048	2000
29	4049	2001
30	4050	2002
31	4051	2003
32	4052	2004
33	4053	2005
34	4054	2006
35	4055	2007
36	4056	2008
37	4057	2009
38	4058	2010
39	4059	2011
40	4060	2012
41	4061	2013
42	6066	1972
43	6069	1973
44	6070	1974
45	6071	1975
46	6072	1976
47	6073	1977
48	6074	1978
49	6075	1979

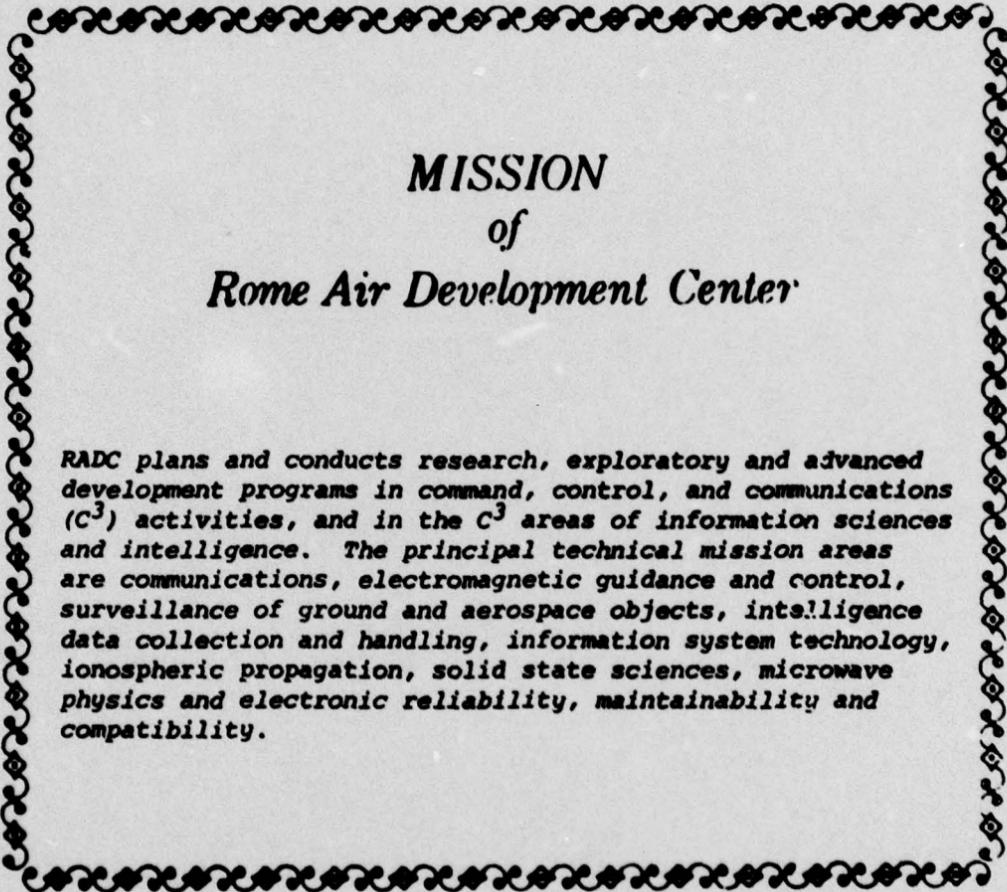
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TARGET IS AT RANGE 50000.0 METERS, BEARING 90.0 DEGREES FROM FLIGHT PATH.
TARGET VELOCITY IS 3.86 METERS/SEC AT RELATIVE BEARING 180.0 DEGREES (RIGHT WING POSITIVE).
LOP RATE IS 50.0 PERCENT.

RADAR IS SET UP AS FOLLOWS\
VELOCITY\ 154.33 METERS/SEC.
PRF\ 250 HERTZ.
CARRIER\ .100E+09 HERTZ.
EACH FFT IS 256 POINTS LONG.
NO= .00 TIMES WCH.
WOOT = 1.05 TIMES WOOTCH.

WE REQUIRE 54 OUTPUTS AS FOLLOWS\
POSITION FFT OUTPUT #

0	256	256
1	512	256
2	1023	255
3	1279	255
4	1790	254
5	2046	254
6	2557	253
7	2813	253
8	3068	252
9	3069	253
10	3324	252
11	3580	252
12	3835	251
13	3836	252
14	4091	251
15	4347	251
16	4602	250
17	4603	251
18	4858	250
19	5114	250
20	5369	249
21	5370	250
22	5625	249
23	6136	248
24	6392	248
25	6903	247
26	7159	247
27	7670	246
28	7926	246
29	8181	245
30	8182	246
31	8437	245
32	8693	245
33	8948	244
34	8949	245
35	9204	244
36	9460	244
37	9715	243
38	9716	244
39	9971	243
40	10227	243
41	10482	242
42	10483	243
43	10738	242
44	11249	241
45	11505	241
46	12016	240
47	12272	240
48	12783	239
49	13040	239



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